Deaver.

The Influence Of The Rate Of Cooling Upon The Toughness Of Paving-Brick Shales.

THE INFLUENCE OF THE RATE OF COOLING UPON THE TOUGHNESS OF PAVING-BRICK SHALES

BY

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THESIS

FOR THE

DEGREE OF BACHELOR OF SCIENCE

IN

CERAMICS

COLLEGE OF ENGINEERING

UNIVERSITY OF ILLINOIS

1916

UNIVERSITY OF ILLINOIS

May 29 1916

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED Influence of the Rate of Cooling Upon the Toughness of Paving Brick Shales

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE

DEGREE OF Bachelor of Science in Ceramics.

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Influence of the Rate of Cooling Upon the Toughness of Paving Brick Shales

The ever increasing use of paving brick, both for city and country paving, has brought this product, with its attendant problems of manufacture, before the eyes of many of the clay manufacturers of this country. Modern traffic demands a paving material, which is resistant to all sorts of weather conditions, which has the ability to withstand the effect of heavy loads instantly applied, and which will exist unchanged under these conditions for long periods of time.

The last of these requirements is probably the most important of the three, and is the one which really determines the value of the product. This property of permanence in a paving brick is dependent upon the toughness of the brick, the degree of which may be determined by an abrasion or " Rattler " test. It is always the object of manufacturers of paving brick to produce the toughest ware possible, that is, one which will show a minimum loss in the rattler test.

The known factors which directly influence the property of toughness are: structure, fineness of grain, tempering, moulding, drying, and burning. One of the important factors, of which the effect is little understood but which directly influences the toughness of the brick, is the cooling. In an investigation of the

effect of different rates of cooling upon paving brick, *Coulter found that within the limits of his test the rate of cooling had no appreciable effect upon the toughness of the brick. In a test of certain bricks burned in a commercial kiln, he found that the most rapidly cooled bricks gave the smallest rattler loss. This may have been due to the composition of this particular clay, but it would indicate that a tougher brick is obtained by preventing any crystallization that might take place during a longer cooling period.

In the investigation of igneous rock, it has been found that a very important factor in the structure and composition is the condition existing during the cooling. This fact is also considered in the annealing of glass and in the tempering of many metals. A vitrified paving brick may be considered as being produced under conditions somewhat similar to those under which igneous rocks were produced. Whether or not the rates of cooling, within the time limits allowed by commercial practice, have any effect upon the structure and toughness of the brick, is an interesting problem.

The present well accepted view among manufacturers of paving brick, with reference to the effect of cooling on the toughness, seems to be that the longer the brick is allowed to cool in the kiln, the tougher it will be, and the better it will stand the rattler test.

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*Coulter. Transactions of the American Ceramic Society, 9, 615.

As there are but few records of accurate tests of the effect of the rate of cooling upon the toughness of a paving brick, and as the property of toughness is one of great importance among the factors governing its life, the present work was undertaken. A shale used commercially was burned to maturing temperature and submitted to an abrasion test to ascertain whether there was any relation between the rate of cooling and the toughness of the burned ware.

Method of Investigation

A. Preparation of trial pieces.

The material from which the trial pieces used in this work, were made was a shale mined at Streator Illinois, and used in the manufacture of vitrified paving brick. The shale is very plastic and easily worked, and vitrifies between Cones 3 and 5 in the test kiln.

The shale was obtained from the plant in a coarsely ground condition, and was ground in a dry pan having 12-mesh screen plates. The ground shale was then tempered in a wet pan and moulded in a small auger brick machine having a circular die 3.5 inches in diameter, lubricated by water under 50 pounds pressure. The clay column was run into a lubricated cutting box and cut with a wire into disks 1.75 inches in thickness. These green disks were dried in the open air for twenty-four hours and were then placed in a small steam heated dryer. They remained in this dryer for twenty-four hours, after which they were ready for burning.

B. Burning of trials.

The burning was carried on in a small, circular, down-draft, oil fired, test kiln, a design of which is shown on page 12. The trial pieces were burned to Cone 3, the cones being set in both the top and bottom of the kiln to insure uniform heat distribution. Care was taken during the burning, to keep uniform temperature conditions thruout the kiln. The temperature readings were made with a Platinum-Rhodium thermocouple and recording millivoltmeter.

Four burns were made, the temperature being raised in each according to the curve shown on page 8. The trials were subjected to a nine hour soaking period, during which the temperature rose from 1050°C to 1100°C. This was done to duplicate to some extent commercial conditions, and also to give the trials a denser structure.

C. Cooling of trials.

The cooling of the kiln in the different burns followed the curves shown on pages 9 and 10. A recording pyrometer was used to give the exact temperature record. The maximum rate of cooling was obtained by opening wide the kiln damper, and allowing the cooling air to be drawn in thru the fire holes into the kiln. In this way the air passed upwards between the bag wall and the kiln wall, thus becoming heated nearly to the kiln temperature before coming into contact with the ware. Because of this fact none of the ware was cracked or checked, even when subjected to the most rapid rate of cooling.

The minimum rate of cooling was obtained by closing the damper in the flue leading from the kiln to the main stack

[illegible]

[illegible]

[illegible]

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flue, and sealing up the fire holes by means of fire-clay slabs. The intermediate rates of cooling were regulated by leaving the fire holes unsealed, and occasionally opening the damper for short periods of time.

All of the trial pieces, when taken from the kiln appeared to be well burned. In all of the burns a uniform heat was obtained in all parts of the kiln.

D. Method of testing.

The trial pieces were submitted to an abrasion test in a small cast iron ball mill, 28 inches in diameter by 16 inches long, rotated at a speed of 42 R. P. M., for a period of 30 minutes. Three hundred pounds of 1.5 inch cast iron balls and ten of the trial disks were used in each charge. The ten trial pieces were weighed before and after testing, and the per cent loss was obtained in terms of the initial weight.

In the case of the trial pieces subjected to the intermediate rates of cooling, several of the trials were broken in the ball mill. In these cases all small pieces were gathered together and weighed, and their weight was added to that of the unbroken pieces.

Two tests were made on the trials taken from each burn. The average loss in percent of total weight is given in the table on page 6.

The porosity of sample pieces, taken from each burn, was determined by the usual formula $\frac{W - D}{W - S} \times 100$, where W is the weight of the piece after soaking in water for twenty-four hours,

and in a vacuum cylinder for forty-eight hours; D represents the weight of the dry piece; S the weight of the piece suspended in water. These porosity determinations are listed in the following table.

Results

Burn	Length of Cooling Period in Hours	Per cent Loss of Weight in rattler Test #1	Test #2	Av. Per cent Loss in Wgt.	Porosity
1	47	35.85	31.44	33.64	11.00
2	37	40.594	38.355	39.47	9.26
3	27	46.385	44.202	45.29	12.74
4	7	23.75	27.40	25.56	8.88

Conclusions

Upon studying the results obtained in this work, the following points are noted. The high porosity of the trial pieces indicates the fact that the shale used in this test, matures at a higher heat treatment than cone 3, and that in order to obtain a vitrified product in the test kiln the burns should have been carried at least one cone higher.

The fact that the lowest abrasion losses were obtained from the trials which were subjected to the maximum and minimum rates of cooling indicates, that there is a certain rate of cooling for every shale which will produce ware of minimum toughness. Change of rate either toward faster or slower cooling, results in an increase of the toughness. This increase seems to be greater as rapid cooling is approached, and probably continues to increase up

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[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

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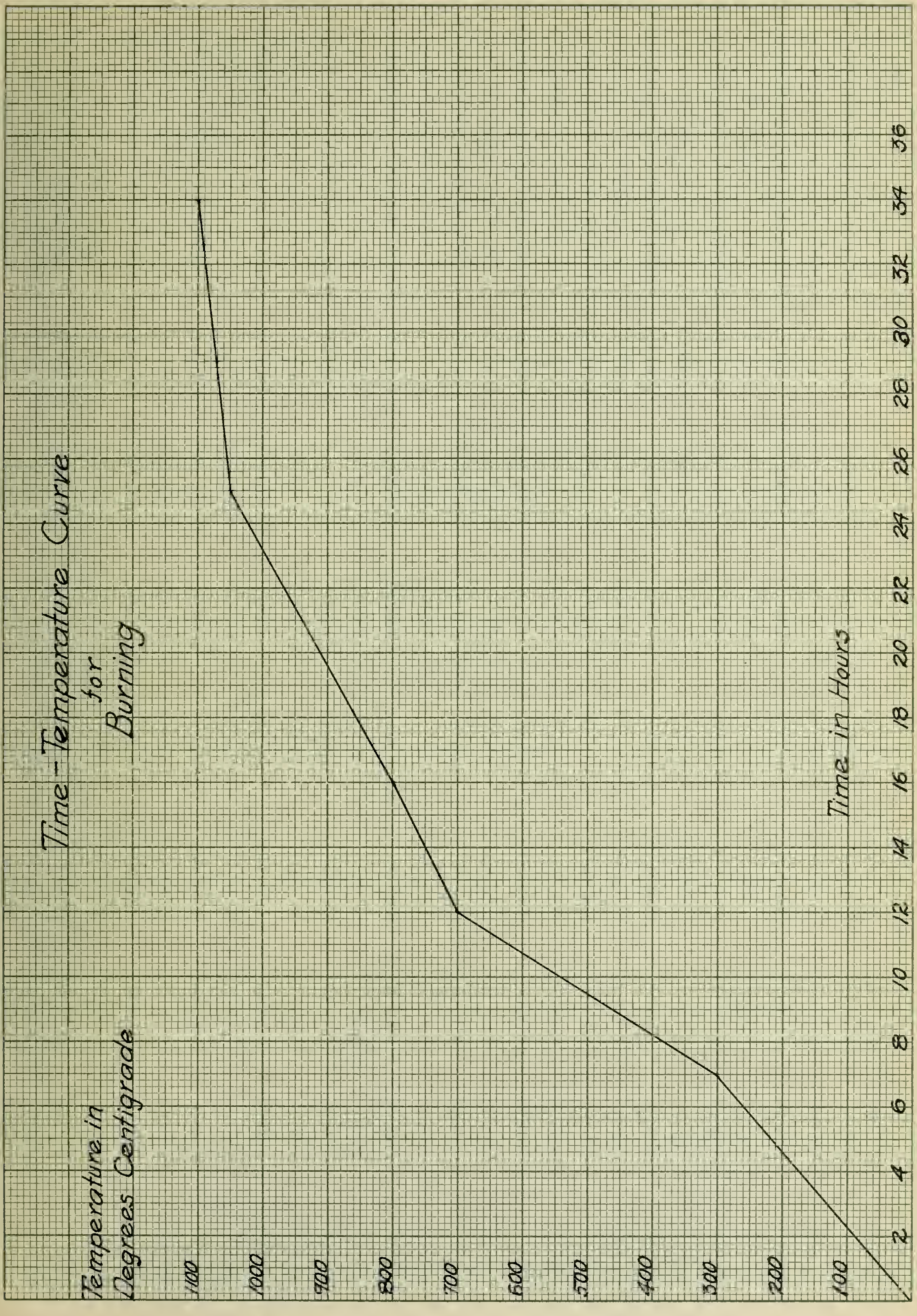
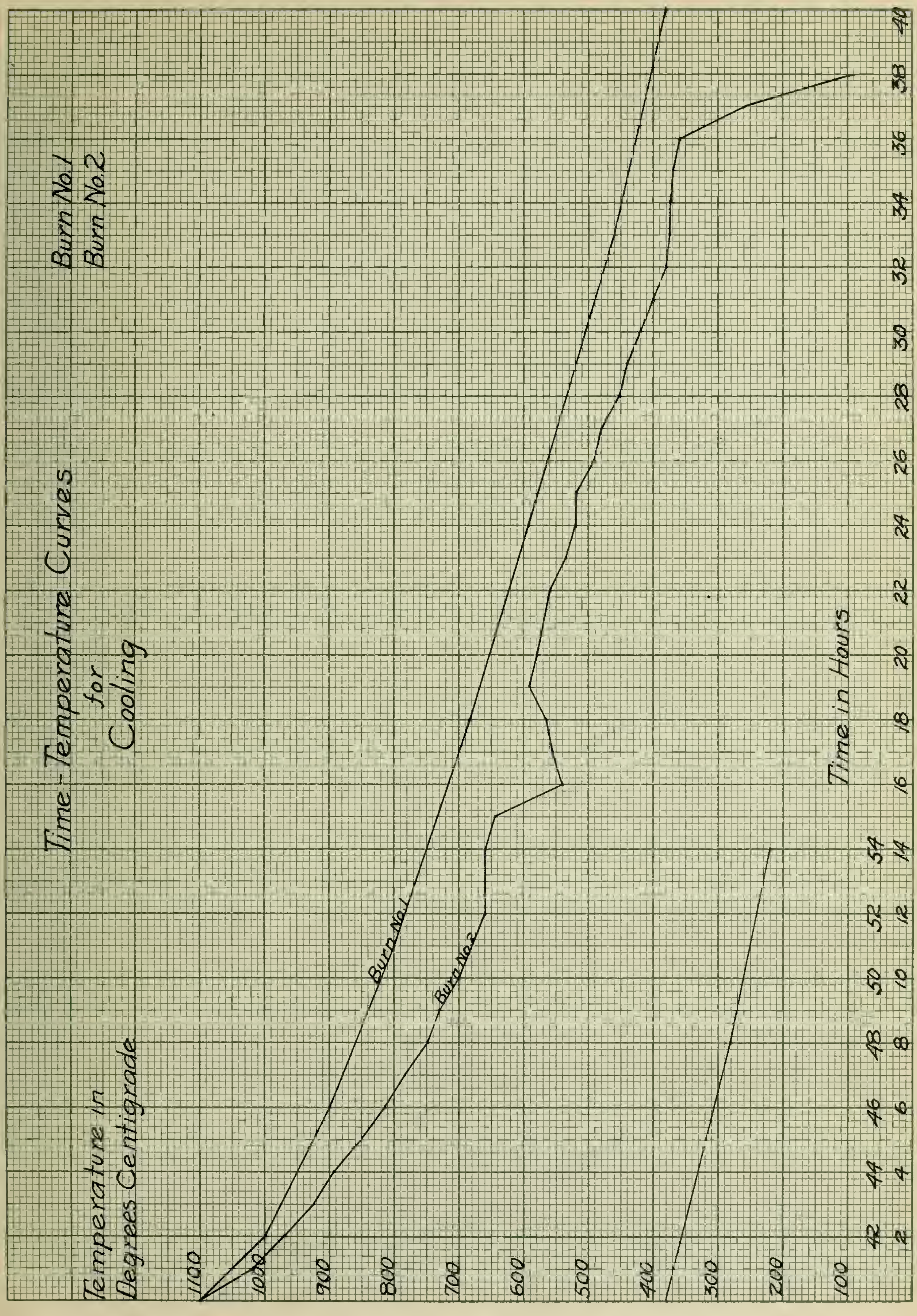
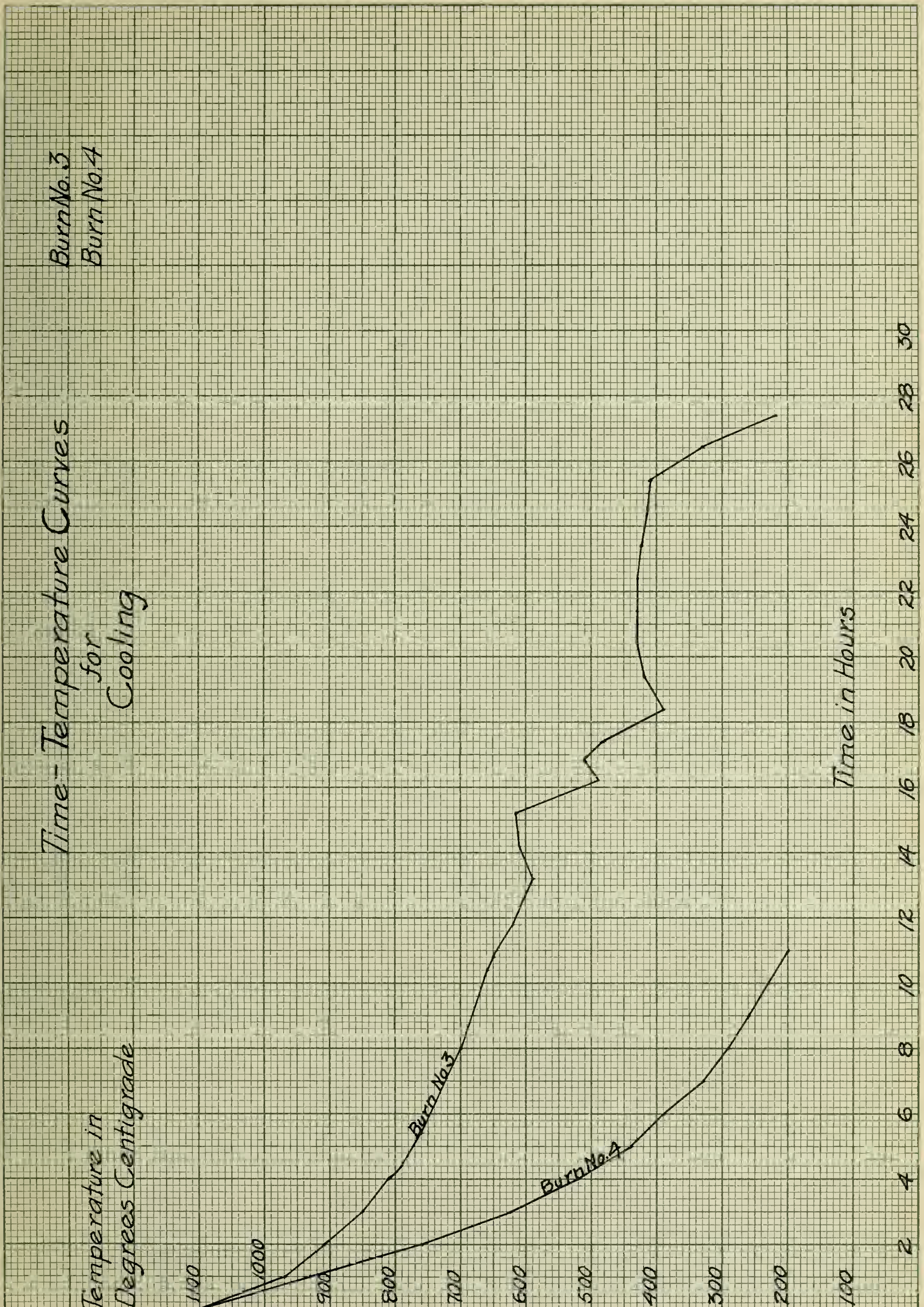
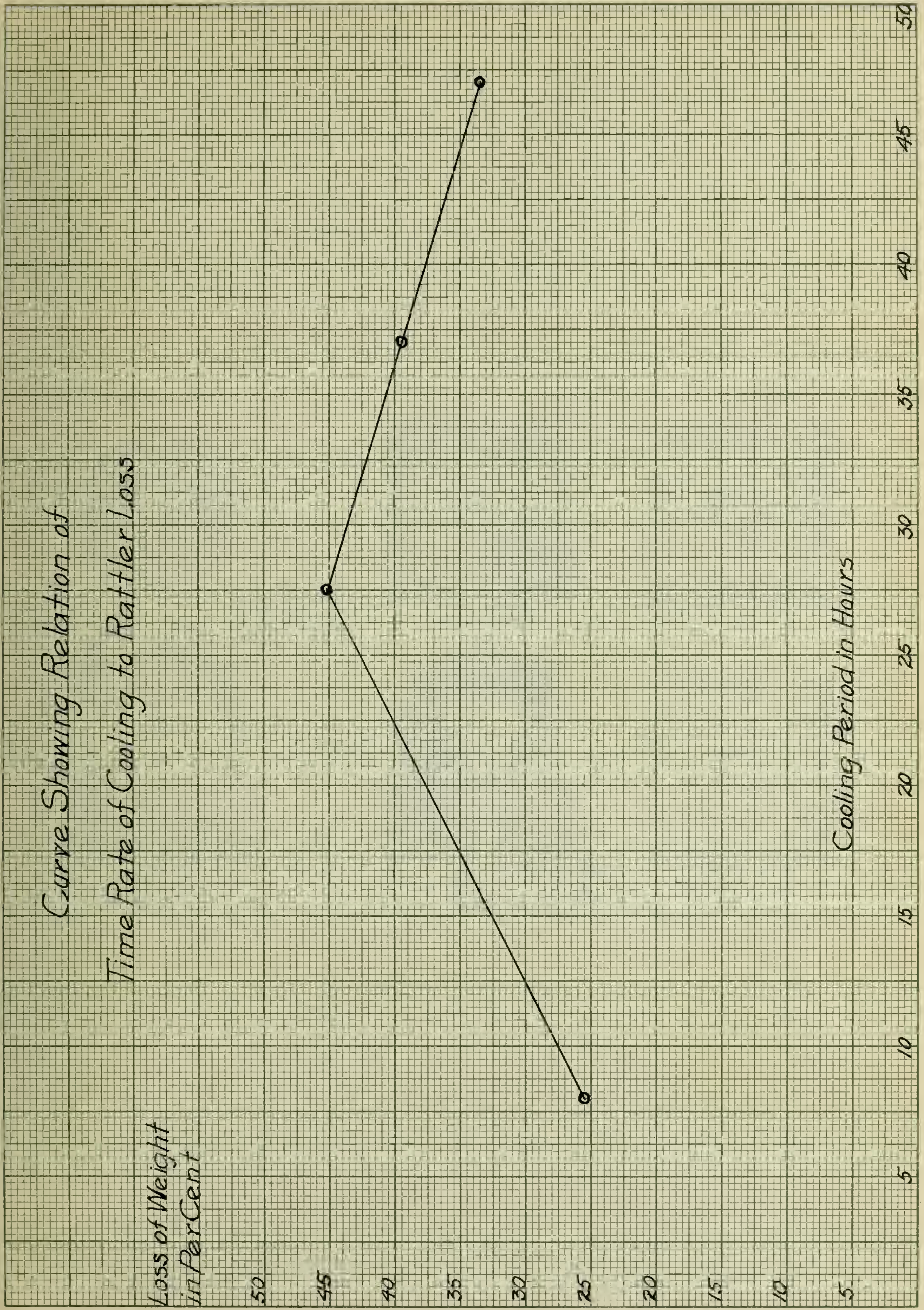
to that rate of cooling which slightly checks or cracks the ware.

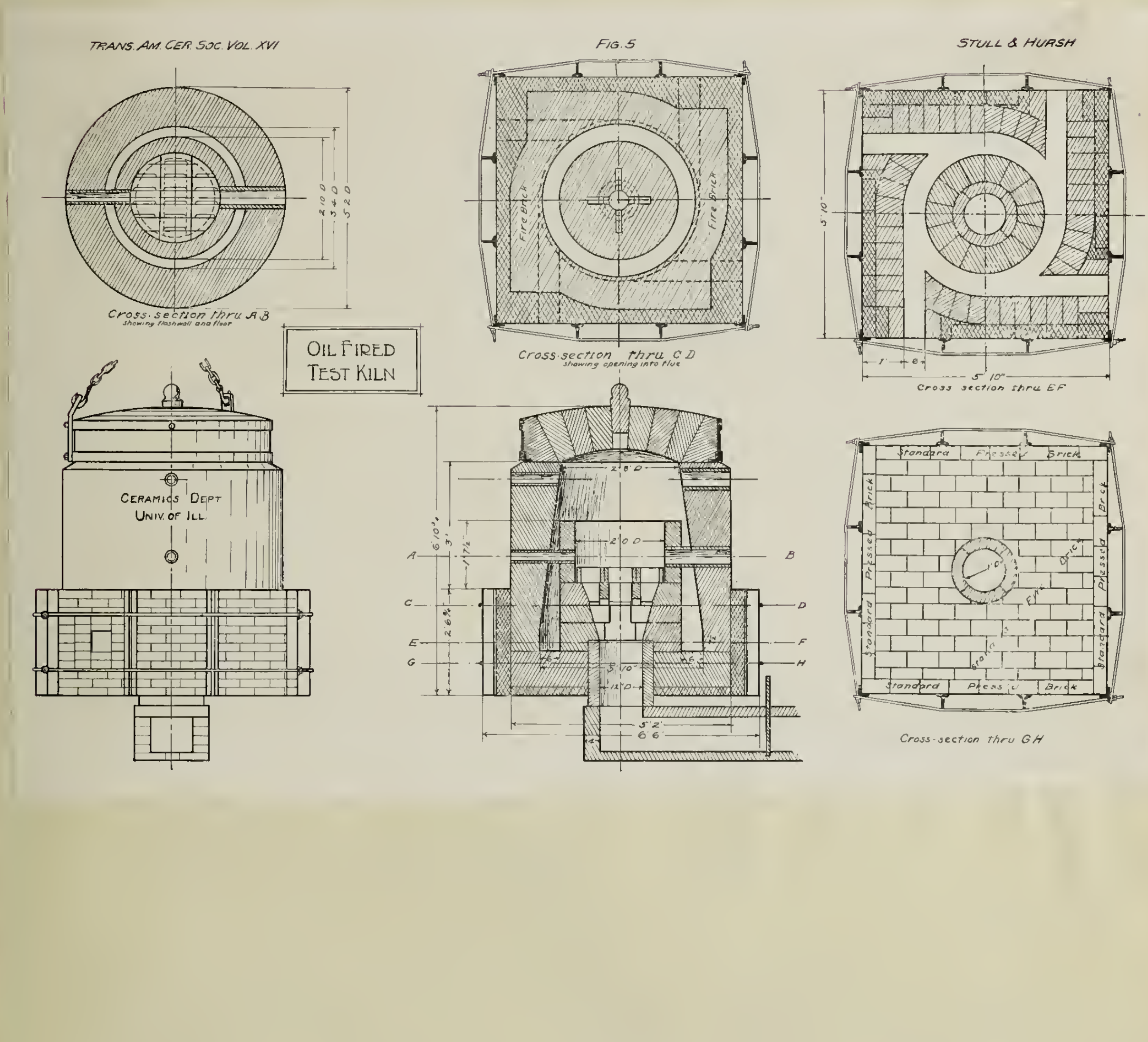
The slower rates of cooling apparently toughened the trial pieces more slowly, but the limit of increase of toughness in this direction was not found in the present study.


Time - Temperature Curve
for
Burning
Temperature in
Degrees Centigrade
Time in Hours
100
200
300
400
500
600
700
800
900
1000
1100
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36


Time-Temperature Curves
for
Cooling
Burn No.1
Burn No.2
Temperature in
Degrees Centigrade
Time in Hours
1100
1000
900
800
700
600
500
400
300
200
100
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
Burn No.1
Burn No.2


Time-Temperature Curves
for
Cooling
Burn No.3
Burn No.4
Temperature in
Degrees Centigrade
Time in Hours
1100
1000
900
800
700
600
500
400
300
200
100
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
Burn No.3
Burn No.4


Curve Showing Relation of
Time Rate of Cooling to Rattler Loss
Loss of Weight
in Per Cent
50
45
40
35
30
25
20
15
10
5
Cooling Period in Hours
5
10
15
20
25
30
35
40
45
50


TRANS. AM. CER. SOC. VOL. XVI
FIG. 5
STULL & HURSH
Cross-section thru A B
showing flashwall and floor
OIL FIRED
TEST KILN
Cross-section thru C D
showing opening into flue
Cross section thru E F
CERAMICS DEPT
UNIV. OF ILL.
Standard Pressed Brick
Fire Brick
Cross-section thru G H